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DEVELOPMENT OF MICROALGAE BASED BIOREFINERY TO IMPROVE ITS ENERGY EFFICIENCY

Theses summary

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1. Introduction

The application of fossil fuels and the uncontrolled emission of anthropogenic greenhouse gases enhance global warming and climate change. The main motivation of the dissertation is the investigation and development of bio-chemical technologies that contribute to the mitigation of anthropogenic CO_2 emission.

Biorefineries have received a great attention in recent decades due to their carbon dioxide emission mitigating potential. Microalgae based biorefineries are able to produce sustainable biofuels with high energy density and to contribute for achieving a greener economy.

The aims of the dissertation are *(1)* the investigation of energetic efficiency of a microalgae based biorefinery, *(2)* identification of refinery's bottlenecks, *(3)* decreasing the environmental damages of CO_2 capture process, *(4)* increasing the efficiency of microalgae cultivation, *(5)* investigating the relationship between algae cultivation and hydrothermal gasification and *(6)* increasing the yields of hydrothermal gasification via targeted cultivation.

2. Literature review and problem statement

The rapidly growing human population and global energy consumption are elevating the emission of greenhouse gases (GHG). Biorefineries receive high attention due to their global warming and climate change mitigating potential. Microalgae – as a photosynthetic organism - could play a key role in carbon capture and utilization by being able to capture the carbon dioxide from air and/or industrial flue gas sources. Following the biofixation, anthropogenic CO_2 can be converted into valuable platform molecules and/or chemicals such as alternative energy carriers (*e.g.*, biodiesel, bioethanol, biogas), pharmaceutical compounds, food supplements and fertilizers.[1]

Biofuels can be categorized into 3 main categories: *(i)* first generation biofuels are produced from edible crops, *(ii)* second generation fuels are made of energy crops and biological wastes and *(iii)* third generation biofuels are produced from microorganisms.[2] Algae have many attractive characteristics over terrestrial crops, such as high growth rate, photosynthetic efficiency and biomass productivity, it does not compete with food

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[1] Zhu, L., Biorefinery as a promising approach to promote microalgae industry: An innovative framework, Renewable and Sustainable Energy Reviews, 2015, 41:1376-1384, doi: 10.1016/j.rser.2014.09.040

[2] Brennan, L., Owende P., Biofuels from microalgae – a review of technologies for production, processing, and extractions of biofuels and co-products, Renewable & Sustainable Energy Reviews, 2010, 14(2):557-577 doi: 10.1016/j.rser.2009.10.009

market, the composition of cells can be influenced by stress conditions, and it can be cultivated on non-arable land. However, the production of third generation biofuels must overcome several obstacles and difficulties in order to be able to operate biorefineries efficiently. These technological and economic barriers are related to the fermentation of algae biomass which can be carried out in extremely dilute suspensions (0.5-4 g L^{-1}), and to the downstream processing of the cells which includes several complex process units. Algae are capable to absorb the CO_2 content of flue gas which can be injected directly to the culture broth if it does not contain toxic compounds (NO_x, SO_2 and heavy metals) in high concentration. In other cases, interstitial carbon capture process units should be applied for the fixation of CO_2 in order to *(1)* prevent uncontrolled primary GHG emission and to *(2)* provide required carbon source for the culture.

Fossil based power plants are responsible for around 30-40% of the total annual anthropogenic carbon dioxide emission and it is expected that this value is going to increase to approximately 60% by the end of this century.[3] These point like carbon dioxide sources provide a good opportunity for significant and efficient GHG emission reduction. The separated CO_2 can be stored in a geological reservoir and/or transformed into valuable products via bio- and/or chemical methods which is in accordance with the principles of circular economy.

A microalgae-based biorefinery consists of 2 main blocks: upstream and downstream parts. The cells are cultivated and harvested in the upstream section, while the produced biomass is transformed into valuable products in the downstream process chain. Microalgae can be cultivated in open and closed systems. In case of photoautotrophic organisms one of the most important cultivation parameter is the proper illumination of the culture broth. Closed indoor systems require artificial light sources which expands the number of possible influencing factors on cultivation with light's wavelength distribution and intensity. Light emitting diodes (LEDs) emerged recently as one of the most appropriate light sources for microalgae cultivation. LEDs provide longer lifetime and better efficiency compared to high intensity discharge lamps and fluorescent tubes.[4]

Microalgae can be converted into biofuels via several different processes such as

[3] Anwar, M., Fayyaz, A., Sohail, N., Khokhar, M., Baqar, M., Khan, W., Rasool, K., Rehan, M., Nizami, A., CO_2 capture and storage: A way forward for sustainable environment. Journal of Environmental Management, 2018, 226:131–144. doi: 10.1016/j.jenvman.2018.08.009.

[4] Blanken, W., Cuaresma, M., Wijffels, R.H., Janssen, M., Cultivation of microalgae on artificial light comes at cost, Algal Research, 2013, 2:333-340, doi: 10.1016/j.algal.2013.09.004.

fermentation, transesterification, thermochemical and hydrothermal treatments. The advantage of hydrothermal treatments (hydrothermal carbonization, liquefaction and gasification) is that the moisture content of the feedstock can be high because the water acts as a reagent and a solvent in these processes. The benefit of hydrothermal technologies is the elimination of biomass drying step from the refineries scheme resulting in considerable energy savings.

Hydrothermal gasification (also known as supercritical water gasification) is a thermochemical process where fuel gas (H_2, CH_4, CO_2, CO) can be produced at high temperature (T=450-700°C) and pressure (p=221-400 bar).[5] In these conditions the water is in its supercritical condition (supercritical point of water: T_c=374°C, p_c=221 bar). Hydrothermal gasification of wet biomass is already demonstrated on model compounds (*e.g.*, humic acid, cellulose and horse manure).[6] A few studies deal with microalgae biomass where generally the main objectives are the evaluation of different strains and catalysts to raise yields and decrease reaction temperature.[7,8]

The main technological challenges of algae biorefineries are the low product yield and biomass productivity at large scale which highlight the necessity of improving further upstream and downstream technologies. High biomass productivity is required for the scaled up thermochemical conversion route to promote the energy and cost effective processing of microalgae biomass.

3. Applied methods

The energy flows of a microalgae-based biorefinery was determined by investigating the energy requirements and gains of individual process units. In the case of the upstream section these were microalgae cultivation (open raceway-ponds, tubular photobioreactors) and harvesting (flocculation and centrifugation). Two different downstream processing routes were investigated for the production of biodiesel: *(1)* traditional dry route

[5] Gai, C., Zhang, Y., Chen, W-T., Zhang, P., Dong, Y., An investigation of reaction pathways of hydrothermal liquefaction using *Chlorella pyrenoidosa* and *Spirulina platensis*, *Energy conversion and management*, 2015, 96:330-339 doi: 10.1016/j.enconman.2015.02.056
[6] Madenoglu, T.G., Saglam, M., Yüksel, M., Ballice, L., Hydrothermal gasification of biomass modell compounds (cellulose and lignin alkali) and model mixtures, The Journal of Supercritical Fluids, 2016, 115:79-85 doi: 10.1016/j.supflu.2016.04.017
[7] Onwudili, J.A., Lea-Langton, A.R., Ross, A.B., Williams, P.T., Catalytic hydrothermal gasification of algae for hydrogen production: Composition of reaction products and potential for nutrient recycling, Bioresource Technology, 2013, 127:72-80 doi: 10.1016/j.biortech.2012.10.020
[8] Norouzi, O., Safari, S., Jafarian, S., Tavasoli, A., Karimi, A., Hydrothermal gasification performance of Enteromorpha intestinalis as an algal biomass for hydrogen-rich gas production using Ru promoted Fe-Ni/Al_2O_3 nanocatalysts, Energy Conversion and Management, 141:63-71, 2017,
doi: 10.1016/j.enconman.2016.04.083

that includes pretreating of biomass (cell disruption, drying, grinding), lipid extraction, transesterification, atmospheric gasification of lipid depleted algae residue, and additional process units for product purification (solvent recovery) to meet the requirements of alkyl ester-based biodiesel standards (ASTM D6751 and EN14214). The *(2)* wet route or hydrothermal route incorporates the hydrothermal liquefaction unit, bio-oil stabilization and hydroprocessing. The Net Energy Ratios (NERs) of different conversion routes were determined and used to compare biorefinery alternatives and to identify technological bottlenecks.

Cradle-to-gate life cycle analysis (LCA) was used to investigate the environmental effects of monoethanolamine (MEA)-water based Carbon Capture and Storage (CCS) technology. The functional unit of the analysis was 774.5 kg emitted CO_2 via the production of 1 MW electricity. Ecoinvent v3.1 database was used for establishing life cycle inventory. 4 different life cycle impact assessment methods were considered: IPCC 2007, Eco-indicator 99, IMPACT 2002+ and EPS 2000. SimaPro v8.3 software was used to conduct the LCA. PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis was applied in conjunction with Multi-Criteria Decision Analysis (MCDA) with Multi Attribute Value Theory (MAVT) method to examine and screen external factors that can affect the chemical based carbon capture process chain and to rank and select the most appropriate CCS alternative from multiple point of view.

Microalgae biomass (*Chlorella vulgaris*) was cultivated in microtiter plate (MTP) module and laboratory-scale stirred tank photobioreactors. RGB-LEDs was used as external light sources to investigate the effects of illumination wavelength and light intensity. One-way ANOVA was used to evaluate the effects of wavelengths, while Central Composite Design (CCD) and Response Surface Methodology (RSM) was used to determine the effects of light intensity on biomass productivity. The cultivation of algae was monitored by measuring optical density (OD) and dry weight (DW) content of the broth. The produced biomass was transformed into biogas via hydrothermal gasification at 550°C, 300 bar and an average 120 sec residence time in a tubular reactor system. The produced fuel gas was analyzed using a gas chromatograph with TCD and FID detectors.

4. Results and discussion (2-6 o)

The aims of the energy flow calculation were to specify the energetically most beneficial microalgae biorefineries with the most favorable NER values and to identify possible refinery bottlenecks. Throughout the calculations it is found that some of the process units consume significant amount of energy. These are the biomass drying, carbon dioxide absorption, atmospheric gasification of lipid depleted algae residue, hydrothermal liquefaction unit and mixing during cultivation in open raceway ponds and closed tubular photobioreactors. In the case of the dry route, the drying process has the highest impact on the energy balance, its share in the total energy demand is nearly 45%, thus it is required to remove as much water as possible in pre-dewatering steps (flocculation, centrifugation). MEA-based carbon capture has the second largest energy consumption with a share of 22.7%. It highlights the importance of robustness of microalgae species, because the flue gas can be directly injected to the cultivation system if it does not contain toxic compounds in high concentration. The calculations show that refinery configurations that include CO_2 capture has a negative energy balance. Atmospheric gasification of lipid depleted waste has also high energy requirements up to 12.12% but on the other hand the energy gain is 1.68-times higher compared to the transesterification of triacylglycerols into fatty acid alkyl esters. The rest of the processes have a combined energy need of 12.96%. It is determined that the traditional dry route has a negative energy balance with any cultivation systems since in any cases, the total required energy for the transformation of microalgae biomass is higher than the possible energy gain by combusting biofuels. In the case of the wet -hydrothermal – route, the highest energy requirement is paired with the carbon dioxide absorption process (40.44%). The hydrothermal liquefaction unit represents 21.67% of the total energy demand, while algae cultivation related mixing corresponds to 15.44%. 10 different biorefinery configurations are examined (5 different upstream and 2 different downstream options). It is found that 2 scenarios meet the required NER>1 criteria: both alternatives apply hydrothermal technology but different cultivation systems (one with raceway pond, NER=1.109 and one with tubular photobioreactors, NER=1.137). As a conclusion it is found that the wet conversion route is more beneficial from an energetic point of view, while the configurations that apply photobioreactors for the cultivation attain higher NERs compared to open systems. Throughout the energetic evaluation the drying of microalgae biomass, the carbon capture process and the cultivation of microalgae biomass are identified as bottlenecks that affect the efficient operation of third generation biorefineries significantly.

The environmental impacts of the CCS technology are investigated conducting a cradle-to-gate life cycle analysis. It is found that the global warming potential of the CCS technology can be decreased by 278 kg $CO_{2,eq}$ compared to the uncontrolled release of flue gas. On the other hand, multiperspective impact assessment methods (Eco-indicator

99 and IMPACT 2002+) provide contradictory results, *i.e.*, CCS has higher environmental load than the direct release of carbon dioxide by 5.8 and 1.8 times, respectively. These methods show that the highest environmental damages of CCS technology are paired with the application of non-renewable fossil fuels. Two steps are considered to decrease unfavorable environmental effects: *(1)* process improvement (decrease the required energy input for MEA regeneration by applying heat integration) and *(2)* the application of renewable energy sources. Heat integration and proper optimization of absorbent/flue gas ratio can decrease significantly the energy requirements of MEA regeneration process. The recalculated environmental damages show that process improvement contributes to decrease the global warming potential of CCS process by 550.5 kg $CO_{2,eq}$ compared to the uncontrolled CO_2 release. In case of the IMPACT 2002+ multi-perspective method, the overall environmental damage is decreased from 141.2 mPt to 63.3 mPt. However, EI99 method shows contrary results and unfavorable environmental scores in case of CCS technology. In order to make the CCS technology much more beneficial the effects of alternative renewable energy sources (*e.g.*, wood pellets, sugar cane, sweet sorghum, biogas) are investigated as a substitute of fossil fuels for heat generation. It is found that among the investigated renewable energy sources the biogas-based systems have the lowest environmental impacts. Additionally, the CCS technology becomes a much preferable way from environmental point of view comparing it to the uncontrolled release of carbon dioxide in case of all life cycle assessment methods including the multi-perspective ones as well. The total environmental score of the fossil-based CCS alternative is 3.43-fold higher than the renewable based one in case of the IMPACT 2002+ method. Compared to the uncontrolled release of carbon dioxide this ratio is 2.96, therefore it can be stated that using renewables considered to be a much more beneficial option from an environmental point of view compared to the others. The same tendency can be drawn using Eco-indicator 99 LCIA method: the total impact of fossil-based CCS is 3.22-fold, the direct CO_2 release is 1.27-fold higher in comparison with the application of renewable energy carrier.

PESTLE analysis is used to screen the LCA alternatives based on multiple external criteria. Multi-Criteria Decision Analysis (MCDA) is used to determine the most favorable CCS alternative. The renewable based CCS is identified as the most advantageous alternative in regard of social aspects. The least favoured alternative is the basic fossil-based CCS which can be traced back to the application of fossil fuels and the high energy requirements of the MEA absorption process. From technological point of view the CCS

Improved scores the highest among alternatives though there is no significant difference between them. The environmental evaluation shows that the CCS Renewable is the most advantageous choice over the others, while the second best is the CCS Improved. Applying the Multi Attribute Value Theory (MAVT), the renewable based CCS technology is detected as the best alternative considering several external influencing factors with an MAVT score of 0.73. The second best alternative is the CCS Improved which highlights the importance of developing the efficiencies of the carbon capture technology (MAVT Score=0.47). The uncontrolled CO_2 release is scored to a higher MAVT value (0.24) than the CCS Fossil alternative (MAVT Score=0.07), thus the CCS technology becomes beneficial if process improvements or renewables are used throughout the operation.

The light factorial investigation of microalgae cultivation is carried out in microtiter plate (MTP) and stirred tank photobioreactor. The effects of different wavelength settings on biomass productivity of *Chlorella vulgaris* is investigated using the MTP device. The experimental results show that the biomass productivity and dry weight content can be significantly different under various wavelength regimes. The highest dry weight attained with mixed colors (in order: purple (626 nm& 470 nm) > yellow (626 nm & 525 nm) > bluegreen (525 nm & 470 nm) > white (626 nm & 525 nm & 470 nm)). The results suggest that irradiating the cultures with the mixed colors provide higher biomass productivity. In our work the highest biomass productivity attained with dichromatic red and blue LEDs, however, de Mooij et al.[9] found the lowest productivity in case of *Chlamydomonas reinhardtii* with this combination, which suggests the strain specificity of optimal light condition.

2-factorial-5-level Central Composite Design (CCD) of experiment was used to evaluate the effects of light intensity on biomass productivity. Response Surface Methodology was applied for the evaluation of experimental data. The R^2 of the fitted polynomial quadratic response surface is found to be 0.9889 thus the model fits well on the experimental data. The adequacy (normal probability plot, predicted vs. observed values, raw residuals vs. case number plots) of the statistical model is investigated together with a test of lack-of-fit. These tests affirm the applicability of the fitted statistical model. The results indicate that the critical values (where the highest biomass productivity can be estimated) of the statistical model are 241.34 and 95.97 μmol photons m^{-2} s^{-1} for red and

[9] de Mooij, T., Schediwy, K., Wijffels, R.H., Janssen, M., Modelling the competition between antenna size mutant and wild type microalgae in outdoor mass culture, Journal of Biotechnology, 2016, 240:1-13, doi: 10.1016/j.jbiotec.2016.10.009.

blue intensities, respectively. Following the optimization process further experiments were carried out for model verification. It is found that the predicted and measured productivities are not differing significantly, thus it can be stated that the fitted polynomial model is adequate and describes properly the biomass productivity in function of various light intensity levels. Two extremum, namely the photolimitation and photoinhibiton are also observed. These phenomena diminish biomass productivity and thus highlight the importance of optimization.

Scaled-up fermentations are carried out in laboratory scale stirred tank photobioreactors in order to *(1)* justify the results of MTP optimization and *(2)* to investigate different illumination and aeration conditions on biogas yield that produced via hydrothermal gasification. The light intensity and aeration rate are examined at two different levels. The highest final dry weight is found to be 0.644 g L^{-1} at 256.88 and 102.10 µmol photons m^{-2} s^{-1} red and blue light intensity and 0.75 vvm aeration rate. The experimental results suggest that increased light intensity combined with lower aeration levels contribute to achieve higher carbohydrate content while increasing aeration rate provides higher amount of lipids in algal cells.

Hydrothermal gasification of microalgae biomass is carried out in a tubular reactor system at 550°C, 300 bar and an average 120 sec residence time. It is found that the biological composition (lipid, carbohydrate, protein content) of microalgae biomass can influence the biogas quality that produced via the hydrothermal process. The lipid and carbohydrate content of algae cells can be affected in the cultivation phase by changing light intensity and aeration levels, thus targeted cultivation can increase the gas yield and composition of hydrothermal gasification. It is turned out that higher methane yield is achievable by the hydrothermal treatment if the lipid content of the biomass increased during the upstream process. While in case of algae samples within the biological composition shifted towards higher carbohydrate content result in higher hydrogen mole fraction. The highest hydrogen yield is found to be 9.34 mol kg^{-1} which is more than a double increasement (4.38 mol kg^{-1}) and it is achieved throughout the optimization of cultivation parameters without using any catalyst during the HTG process. In the experimental section fermentations with increased biomass productivity are paired with high lipid content of microalgae biomass which contribute elevating methane yield (from 0.35 to 1.68 mol kg^{-1}). As a conclusion, the results show that gas yield elevates via light intensity optimization, thus the cultivation parameters are determinant factors which should be considered not only in upstream technologies but in the downstream stage as well because the overall efficiency of the biorefinery can be upgraded further. Different cultivation settings can indirectly influence the obtainable amount of H_2 and CH_4 gases, therefore, targeted cultivation should be implemented in an operation of a biorefinery to raise efficiencies.

5. Theses

Thesis 1 [I, IV, V, VII]

I determined the energy flow of autotroph microalgae based biorefineries containing of different cultivation systems and downstream processing routes. I identified their bottlenecks that are mainly responsible for the efficiency decrease. These elements of the refinery are the drying, CO_2 absorption, atmospheric gasification, hydrothermal treatment and hydrodinamics in cultivation systems. I determined that energy gain is achievable through the utilization of tubular photobioreactors and hydrothermal conversion technologies.

Thesis 2 [II, VIII]

I developed the carbon capture related biorefineries. Applying life cycle analysis, I detected that the Global Warming Potential of the CO_2 capture and storage process chain can be decreased by 71% if the MEA-Water absorbent regeneration is more efficient due to heat integration. The CO_2 capture shows reduced environmental effects by 67% in the case of multiperspective Eco-indicator 99 method if renewables are applied and fossil energy carriers are excluded.

Thesis 3 [II, VIII]

I developed an algorithm for the comprehensive study of Carbon Capture and Storage technology. I expanded the environmental assessment of the CCS chain by external factors using PESTLE analysis and I applied Multi-Criteria Decision Analysis for ranking and selecting CCS alternatives. I identified the renewables based technology as the best carbon capture process alternative comparing it to the fossil and improved CCS alternatives and to the uncontrolled release of CO_2.

Thesis 4 [III, VI, IX]

I determined the best artificial illumination condition for *Chlorella vulgaris* MACC555 microalgae strain to increase its biomass productivity. This can be completed with the dichromatic light emitting diodes (LED) working at 626 nm and 470 nm using optimized light intensity levels at 241.34 and 95.97 μmol photon m^{-2} s^{-1}, respectively.

Thesis 5 [III, IX]

I determined that the lipid content of *Chlorella vulgaris* MACC555 can be favourably influenced by the parameters of light intensity and aeration level in stirred tank photobioreactor at 250 rpm stirring rate. Increasing the aeration level from 0.50 to 0.75 vvm elevates the lipid content by 1.75-times but decrease the carbohydrate content by 2.34-times at optimized light intensity levels.

Thesis 6 [III, IX, X]

I determined that the light factorial optimization and ideal aeration levels of *Chlorella vulgaris MACC555* cultivation can improve the composition and yield of biogas produced by hydrothermal gasification of the feedstock. I determined that the hydrogen yield can be raised by 4.96 mol kg^{-1} if the carbohydrate content of the cells increased by 2.34-times.

6. Fields of application

The PESTLE and Multi-Criteria Decision Analysis that was applied for the evaluation of external factors in case of Carbon Capture and Storage technology can be used for the examination of other chemical processes as well. The developed algorithm facilitates proper decision making resulting in a more accurate overall analysis and final decision making regarding chemical processes.

The application of ideal illumination conditions in case of microalgae cultivation increase biomass productivity which contribute to achieve a more efficient operation. The biogas yield can be increased by applying targeted cultivation which increase the overall efficiency and margins of a microalgae based biorefinery and contribute to achieve a rentable operation.

7. Publications

Publications related to the thesis

I. Fozer, D., Valentinyi, N., Racz, L., Mizsey, P., Evaluation of microalgae-based biorefinery alternatives, *Clean Technologies and Environmental Policy*, 2017, 19(2) 501-515. doi: 10.1007/s10098-016-1242-8 (IF_{2016}=3.331, Q1, I=8)

II. Fozer, D., Sziraky, F.Z., Racz, L., Nagy, T., Tarjani, A.J., Toth, A. J., Haaz, E., Benko, T., Mizsey, P., Life cycle, PESTLE, and Multi-Criteria Decision Analysis of CCS process alternatives, *Journal of Cleaner Production*, 2017, 147, 75-85. doi: 10.1016/j.jclepro.2017.01.056 (IF=5.651, D1, I=11)

III. Fozer, D., Kiss, B., Lorincz, L., Szekely, E., Mizsey, P., Nemeth, A., Improvement of microalgae biomass productivity and subsequent biogas yield of hydrothermal gasification via optimization of illumination, *Renewable Energy*, 2019, 138:1262-1272 doi: 10.1016/j.renene.2018.12.122 (IF=4.900, D1)

IV. Fozer, D., Valentinyi, N., Racz, L., Mizsey, P., Harmadik generációs biofinomítói alternatívák értékelése, *Ipari Ökológia*, 2016, 3-22 (in Hungarian), doi:-

Oral presentations

V. Fozer, D., Valentinyi, N., Racz, L., Mizsey, P., Harmadik generációs – mikroalgán alapuló – biofinomítói alternatívák értékelése, *XXXIX. Kémiai Előadói Napok*, **17.10.2016**, Szeged, Hungary (in Hungarian)

VI. Fozer, D., Kiss, B., Nemeth, A., Determine optimal growth conditions for *Chlorella vulgaris*, *Proceedings of the 12th Fermentation Colloquium*, **19-21.10.2016**, Keszthely, Hungary (in Hungarian)

VII. Fozer, D., Mizsey, P., Mikroalgák az energiaiparban, egy harmadik generációs biofinomító energiamérlege, *MTA Vegyipari Műveleti és Gépészeti Munkabizottság és az MKE Műszaki Kémiai Szakosztály ülése*, **08.06.2017** Budapest, Hungary, (in Hungarian)

VIII. Fozer, D., Sziraky, F.Z., Racz, L., Nagy, T., Tarjani, A.J., Toth, A. J., Haaz, E., Benko, T., Mizsey, P., Life cycle and PESTLE analysis of CCS alternatives, *7th European Young Engineers Conference*, **23-25.04.2018**, Warsaw, Poland

IX. Fozer, D., Farkas, C., Kiss B., Lorincz L., Toth AJ., Andre, A., Nagy, T., Tarjani AJ., Haaz, E., Valentinyi, N., Nemeth, A., Szekely, E., Mizsey, P., The investigation and improvement of hydrothermal gasification parameters on microalgal biomass, *7th European Young Engineers Conference*, **23-25.04.2018**, Warsaw, Poland

X. Fozer, D., Mizsey, P., Szén-dioxid megkötés és hatékony hasznosítása mikroalga alapú technológiával, *Magyar Kémikusok Egyesülete BAZ megyei Területi Szervezete és a*

Miskolci Akadémiai Bizottság Vegyészeti Szakbizottsága - 35. Borsodi Vegyipari Nap, **22.11.2018**, Miskolc, Hungary (in Hungarian)

XI. Fozer, D., Sztancs, G., Kiss, B., Toth A.J., Nemeth A., Nagy, T., Mizsey P., Hydrothermal carbonization of *Chlorella vulgaris* for upgrading the yields of hydrothermal gasification, *Application of supercritical fluids 2018*, **17.05.2018**, Budapest, Hungary

XII. Fozer, D., Sztancs, G., Kiss B., Toth A.J., Haaz E., Nemeth A., Mizsey P., Biogáz előállítás *Chlorella vulgaris* és *Chlorella zofingiensis* hidrotermális elgázosításával, *III. Gazdálkodás és Menedzsment Tudományos Konferencia 2018*, **27.09.2018**, Kecskemét, Hungary, (in Hungarian)

XIII. Fozer, D., Toth, A.J., Kiss, B., Nagy, T., Nemeth, A., Mizsey, P., Hydrothermal Gasification of *Chlorella vulgaris* and *Chlorella zofingiensis* for the Production of Fuel Gases, *51th GOMA Fuels Symposium*, **17-19.10.2018**, Opatija, Croatia

XIV. Fozer, D., Greenery - Közösségi alapú zöldhálózati információs rendszer, *Klímakonferencia - Klímastratégia és éghajlatváltozási platform létrehozása Budapesten*, **17.11.2017**, Budapest, Hungary (in Hungarian)

Other Publications

XV. Cespi, D., Passarini, F., Cavani, F., Volanti, M., Neri, E., Mizsey, P., Fozer, D., Terephthalic acid from renewable sources: early stage sustainability analysis of a bio-PET precursor, *Green Chemistry*, 2019, doi: 10.1039/C8GC03666G (IF=8.586, D1)

XVI. Andre, A., Nagy, T., Toth, A.J., Haaz, E., Fozer, D., Tarjani, A.J., Mizsey, P., Distillation contra pervaporation: comprehensive investigation of isobutanol-water separation, *Journal of Cleaner Production*, 2018, 187:804-818., doi: 10.1016/j.jclepro.2018.02.157 (IF=5.651, D1, I=1)

XVII. Tarjani, A.J., Toth, A.J., Nagy, T., Haaz, E., Valentinyi, N., Andre, A., Fozer, D., Mizsey, P., Thermodynamic and Exergy Analysis of Energy-Integrated Distillation Technologies Focusing on Dividing-Wall Columns with Upper and Lower Partitions, *Industrial & Engineering Chemistry Research*, 2018, 57(10):3678-3684
doi: 10.1021/acs.iecr.7b04247 (IF=3.141, D1, I=2)

XVIII. Toth, A.J., Haaz, E., Valentinyi, N., Nagy, T., Tarjani, A.J., Fozer, D., Andre, A., Selim, A., Solti, Sz., Mizsey, P., Selection between separation alternatives: Membrane Flash Index (MFLI), *Industrial & Engineering Chemistry Research*, 2018, 57(33):11366-11373,
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XIX. Racz L., Fozer D., Nagy T., Toth A.J., Haaz E., Tarjani A.J., Andre A., Selim A.K.M., Valentinyi N., Mika L.T., Deak, Cs., Mizsey, P., Extensive comparison of biodiesel production

alternatives with Life Cycle, PESTLE and Multi-Criteria Decision Analyses, *Clean Technologies and Environmental Policy*, 2018, 20(9):2013-2024,
doi: 10.1007/s10098-018-1527-1 (IF=2.337, Q2, I=1)

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xxi. Haaz E., Valentinyi N., Tarjani A.J., Fozer D., Andre A., Selim A.K.M., Rahimli F., Nagy, T., Deak Cs., Mizsey P., Toth A.J., Platform molecule removal from aqueous mixture with organophilic pervaporation: experiments and modelling, *Periodica Polytechnica-Chemical Engineering*, 2019, 63:138-146., doi: 10.3311/PPch.12151 (IF=0.877, Q3)

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